



INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

<p>(51) International Patent Classification ⁶ : A61B 17/36</p>	<p>A1</p>	<p>(11) International Publication Number: WO 99/15093</p> <p>(43) International Publication Date: 1 April 1999 (01.04.99)</p>
<p>(21) International Application Number: PCT/US98/20033</p> <p>(22) International Filing Date: 21 September 1998 (21.09.98)</p> <p>(30) Priority Data: 60/059,449 22 September 1997 (22.09.97) US 09/087,113 28 May 1998 (28.05.98) US</p> <p>(71) Applicant: FEMRX, INC. [US/US]; 1221 Innsbruck Drive, Sunnyvale, CA 94089 (US).</p> <p>(72) Inventors: LITTLE, William, A.; 15 Crescent Drive, Palo Alto, CA 94301 (US). SAPOZHNIKOV, Igor; 7100 Rainbow Drive #11, San Jose, CA 95129 (US). THOMPSON, Todd; 8172 Moller Ranch Drive, Pleasanton, CA 94588 (US). SAVAGE, George, M.; 1180 Westridge Drive, Portola Valley, CA 94028 (US).</p> <p>(74) Agents: HESLIN, James, M. et al.; Townsend and Townsend and Crew LLP, 8th floor, Two Embarcadero Center, San Francisco, CA 94111 (US).</p>		<p>(81) Designated States: JP, European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).</p> <p>Published <i>With international search report. Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.</i></p>
<p>(54) Title: CRYOSURGICAL SYSTEM AND METHOD</p> <div data-bbox="457 1134 1117 1696"> </div> <p>(57) Abstract</p> <p>A cryosurgical system comprises a compressor unit (14), and a probe assembly (12). A secondary refrigerant stream from the compressor unit (14) pre-cools a heat exchanger (26) within the probe assembly (12) in a standby mode of operation. After the heat exchanger (26) is pre-cooled, a primary refrigerant stream can be passed through the cooled heat exchanger (26), and thereafter expanded within a tissue contacting portion (32) of the probe assembly (12) to achieve very low temperatures, typically minus 100 degrees Celsius or lower. After cooling, the refrigerant stream may be passed through the probe assembly (12) with no or partial expansion to warm the tissue contacting surface (32) of the probe. A probe sheath (40) can be used to provide sterility.</p>		

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	ES	Spain	LS	Lesotho	SI	Slovenia
AM	Armenia	FI	Finland	LT	Lithuania	SK	Slovakia
AT	Austria	FR	France	LU	Luxembourg	SN	Senegal
AU	Australia	GA	Gabon	LV	Latvia	SZ	Swaziland
AZ	Azerbaijan	GB	United Kingdom	MC	Monaco	TD	Chad
BA	Bosnia and Herzegovina	GE	Georgia	MD	Republic of Moldova	TG	Togo
BB	Barbados	GH	Ghana	MG	Madagascar	TJ	Tajikistan
BE	Belgium	GN	Guinea	MK	The former Yugoslav Republic of Macedonia	TM	Turkmenistan
BF	Burkina Faso	GR	Greece	ML	Mali	TR	Turkey
BG	Bulgaria	HU	Hungary	MN	Mongolia	TT	Trinidad and Tobago
BJ	Benin	IE	Ireland	MR	Mauritania	UA	Ukraine
BR	Brazil	IL	Israel	MW	Malawi	UG	Uganda
BY	Belarus	IS	Iceland	MX	Mexico	US	United States of America
CA	Canada	IT	Italy	NE	Niger	UZ	Uzbekistan
CF	Central African Republic	JP	Japan	NL	Netherlands	VN	Viet Nam
CG	Congo	KE	Kenya	NO	Norway	YU	Yugoslavia
CH	Switzerland	KG	Kyrgyzstan	NZ	New Zealand	ZW	Zimbabwe
CI	Côte d'Ivoire	KP	Democratic People's Republic of Korea	PL	Poland		
CM	Cameroon	KR	Republic of Korea	PT	Portugal		
CN	China	KZ	Kazakstan	RO	Romania		
CU	Cuba	LC	Saint Lucia	RU	Russian Federation		
CZ	Czech Republic	LI	Liechtenstein	SD	Sudan		
DE	Germany	LK	Sri Lanka	SE	Sweden		
DK	Denmark	LR	Liberia	SG	Singapore		
EE	Estonia						

CRYOSURGICAL SYSTEM AND METHOD

5

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to systems and methods for performing cryosurgery. More particularly, 10 the present invention relates to use of a closed refrigeration system for cooling a surgical probe to very low temperatures in an efficient and rapid fashion.

Cryosurgery has been used for a number of years for the treatment and ablation of tissue for a variety of 15 therapeutic purposes. For example, cryosurgical probes have been used for ablation of the endometrial lining of the uterus for the treatment of bleeding and other disorders. Most cryosurgical systems rely on either liquid nitrogen or nitrous oxide as a coolant medium. Liquid nitrogen is advantageous 20 since it can achieve very low temperatures, but requires extensive insulation in order to protect the patient and physician from the liquid nitrogen while it is being introduced to the treatment site. Moreover, since the liquid nitrogen is evaporated and released into the atmosphere, 25 continual replenishment of the liquid nitrogen source is necessary. Nitrous oxide is advantageous since it can be delivered at room temperature, thus reducing the requirement for insulation, and be cooled at the treatment site by Joule-Thomson expansion. The temperatures achieved by nitrous oxide 30 expansion, however, are not nearly as low as those achieved with liquid nitrogen, and the use of nitrous oxide also suffers from the need for continual replenishment.

An improvement over the use of liquid nitrogen and nitrous oxide is proposed in U.S. Patent No. 5,275,595 to 35 Dobak, III. In particular, it is proposed that a closed refrigeration system be employed together with a counter-current heat exchanger in the probe of a cryosurgical device. The patent asserts that use of particular refrigerant gas

mixtures can achieve very low temperatures suitable for many forms of cryosurgery.

The system of Dobak, III, however, suffers from a number of disadvantages. In particular, use of the counter-current heat exchanger shown in the patent requires that
5 system equilibrium be established before the lowest system temperatures can be achieved. Thus, the system must be running for some time before useful temperatures can be achieved. Second, the system of Dobak, III provides no means
10 for warming the probe after it has been cooled. Many forms of cryosurgery benefit from repeated heat/thaw cycles, where the ability to heat the probe between successive cool cycles would be desirable. Further, Dobak, III proposes a probe having vacuum insulation over its exterior. The vacuum insulation,
15 however, is shown to be on the probe only and will thus have a relatively small total volume, i.e., the volume is limited to the annular space between the coaxial members that make up the probe. Vacuum insulation in this and other systems with such low volumes suffer excessively from out-gassing (since the
20 internal surface area from which the gas evolves is large compared to the volume available to accommodate the gas) which can lessen or destroy the insulating capability. Finally, Dobak, III proposes no means for sterilizing the probe system. The probe and compressor of Dobak, III will presumably be a
25 closed, sealed system. The sterilization of the probe in such a system will be problematic.

For these reasons, it would be desirable to provide improved closed refrigeration systems for performing cryosurgery. In particular, it would be desirable to provide
30 cryosurgical refrigeration systems which can be pre-cooled in a standby mode prior to use. Full probe cooling from the standby mode will preferably be achieved within several minutes or less, under thermal load. It would further be desirable to provide cryosurgical refrigeration systems which
35 can heat the tissue-contacting probe surface between successive cooling cycles. More preferably, the ability to heat the probe will be achieved using components of a refrigeration system which are already available. Moreover,

it will be desirable to provide closed cryosurgical refrigeration systems where sterilization of the probe components of such systems is facilitated, or the need to sterilize the probes is eliminated. Still further, it would
5 be desirable to provide vacuum-insulated cryosurgical probes which are less prone to out-gassing and loss of vacuum insulation. At least some of these objectives will be met by different aspects of the present invention.

10 2. Description of the Background Art

U.S. Patent No. 5,275,595 describes a cryosurgical probe which is cooled by a refrigeration system. U.S. Patent Nos. 5,644,502 and 5,617,739 describe refrigerants and refrigeration systems of a type which could be employed as a
15 part of the systems of the present invention. Cryosurgical treatment of the uterine endometrium and often other tissue is described in a number of patents and medical publications, including U.S. Patent Nos. 5,647,868; 5,520,682; 5,501,681; 5,403,309; 5,400,602; 5,494,039; 5,207,674, 5,139,496;
20 3,924,628; and 3,889,680. Other cooled medical probes are described in U.S. Patent Nos. 4,844,073; WO 93/06985; WO 93/08951; and WO 83/03961. Use of particulate microcrystalline material, e.g. diamond suspended in a fluorocarbon or paraffin, as a heat transfer material is
25 described in U.S. Patent No. 4,764,845.

The use of multi-component gas mixtures in compressor systems is described in Kleemenko (1959) *Proc. 10th Intl. Congress of Refrigeration*, Copenhagen 1:34-39, Pergamon Press, London; Little (1990) *Adv. Cry. Engineering* 35:1305-
30 1314 and 1325-1333.

SUMMARY OF THE INVENTION

Systems according to the present invention comprise a compressor which produces a recirculating refrigerant
35 stream. The compressor may comprise any conventional system, but will preferably comprise systems according to the teachings of U.S. Patent Nos. 5,644,502, and 5,617,739, the full disclosures of which are incorporated herein by

reference. In addition to such compressors, the systems of the present invention will comprise a probe assembly having a tissue-contacting surface and a primary expansion orifice. The probe is connected to the compressor to receive high pressure refrigerant and to pass said high pressure refrigerant through the primary expansion orifice. Such expansion produces cooling of the tissue-contacting surface and results in low pressure cooled refrigerant which is returned to the compressor.

10 In a first aspect, the system of the present invention will further comprise means for selectively circulating a warm fluid typically refrigerant from the compressor, through the probe to warm the tissue-contacting surface, usually between successive cooling cycles. The warm
15 fluid circulating means typically comprises conduit from the compressor to the probe for passing, but not expanding or only partially expanding a portion of the recirculating refrigerant stream past the tissue-contacting surface. The warm refrigerant may be at or slightly above or below room
20 temperature, but will preferably be well above the typical operating temperatures of the probe for cryosurgery. Usually, the warm refrigerant will be above 0°C, preferably being above 10°C, often being above 20°C, or higher. Usually, the system of the present invention will include a controller to direct
25 passage of a high pressure refrigerant from the compressor to the primary expansion orifice in order to stop active cooling and then initiate flow of the warm refrigerant in order to start warming of the tissue-contacting surface of the probe.

In a second aspect, the system of the present
30 invention will comprise a heat exchanger disposed to pre-cool at least a portion of a primary stream of the recirculating refrigerant which is being directed to the probe for expansion and cooling of the tissue-contacting surface. Means will further be provided for pre-cooling the heat exchanger prior
35 to passing the primary probe refrigerant stream therethrough. In the exemplary embodiment, the pre-cooling means comprises a separate refrigeration loop from the compressor and through a secondary expansion orifice in the heat exchanger. The heat

exchanger is upstream and isolated from the tissue-contacting surface of the probe, so the heat exchanger can be cooled to low temperatures without affecting the temperature of the tissue-contacting surface of the probe. As described in more detail below, the heat exchanger will usually be in a vacuum enclosure which acts to insulate the heat exchanger, in addition to its being isolated from the tissue-contacting surface. Thus, the heat exchanger can be pre-cooled by expanding a secondary stream or portion of the recirculating refrigerant through the secondary expansion orifice and passing the resulting cooled, expanded refrigerant through the heat exchanger, typically until a temperature below minus 60°C is achieved. The primary refrigerant stream may then be directed through the heat exchanger, where it is pre-cooled to a target temperature, in the range from minus 10°C to minus 110°C, typically minus 60°C, prior to expansion in the probe tip adjacent to the tissue-contacting surface. By pre-cooling the refrigerant, very low temperatures, typically below minus 100°C, can thus be achieved at the tissue-contacting surface of the probe. As a particular benefit, the probe tip can be cooled from room temperature to these very low temperatures very quickly, i.e., within several minutes.

Preferably, the heat exchanger and the probe are present in a common, hand-held assembly and connected to a separate compressor unit through a flexible connector. The heat exchanger preferably comprises a coiled shell with one or more coiled inner tube(s). The high pressure refrigerant passes through the inner tube(s) in a direction toward the probe, and the expanded pre-cooling refrigerant stream passes in the opposite direction in an annular space between the inner tube and the shell. The coil geometry is advantageous since it allows relatively long lengths for the counter-current heat exchanger to be incorporated into small cylinders.

In another aspect, the system of the present invention further comprises a sheath adapted for removable placement over the probe. The sheath can be disposable and thus eliminate the need for sterilization of the probe or any

other portion of the compressor/probe system. Placement of a sheath over cryogenic probes has generally been avoided because of loss of heat-transfer efficiency, but the highly efficient refrigeration systems of the present invention at least in part obviate that concern. Moreover, the heat transfer is improved in the systems of the present invention by providing a heat conductive material between an exterior surface of the probe and an interior surface of the sheath. A preferred heat conductive material comprises a heat conductive powder, such as a diamond or graphite powder, suspended in a liquid carrier. By using such heat conductive materials, typically together with minimum clearance between the probe exterior and sheath interior, usually less than 0.15 mm, adequate heat transfer rates can be achieved.

In yet another aspect, the system of the present invention comprises a vacuum enclosure extending over all exterior portions of the probe except for the tissue-contacting surface. Preferably, the vacuum enclosure will cover not only the probe but also the heat exchanger which is connected to the probe. As the heat exchanger will generally have a much larger volume than the probe, the combined volumes of the probe interior and the heat exchanger lessen problems (vacuum degradation) which result from out-gassing of very small probe vacuum volumes.

The present invention further provides methods comprising recirculating a refrigerant from a compressor through a probe and expanding the refrigerant to cool a surface of the probe. The cooled surface is then contacted against tissue for a variety of cryosurgical procedures, such as ablation of the uterine endometrial lining.

In a first aspect, the method of the present invention further comprises circulating a warm fluid from the compressor through the probe to warm the tissue-contacting surface after it has been cooled. Preferably, the warm fluid comprises a portion of the recirculating refrigerant which is passed through the probe without expansion. Usually, the warm fluid will not pass through the heat exchanger in order to avoid warming the heat sink therein.

In another aspect, the method of the present invention further comprises pre-cooling a heat exchanger connected to the probe prior to expanding the primary refrigerant. The primary refrigerant is then passed through
5 the pre-cooled heat exchanger prior to expansion in the probe in order to enhance cooling. Usually, the pre-cooling step comprises passing a secondary stream of the refrigerant through an expansion orifice and directing the cooled, expanded refrigerant through the heat exchanger. Also
10 preferably, the heat exchanger is cooled to a temperature of minus 30°C or below, often minus 60°C or below, prior to passing the probe refrigerant therethrough. Still more preferably, these methods result in a probe which is cooled to a temperature of minus 100°C or below.

15 In yet another aspect, the method of the present invention further comprises covering the probe with the sheath prior to contacting the cooled surface against tissue. Preferably, a heat conductive material is placed between an outer surface of the probe and an inner surface of the sheath
20 to enhance heat transfer. Still more preferably, the heat conductive material comprises a heat conductor powder suspended in a liquid carrier. Optionally, a heat conductive liquid, gel, or other material, can be used to coat, fill, or otherwise occupy at least a portion of the uterus or other
25 body cavity being treated. Preferably, the material will not freeze at the expected treatment temperature and will conform to both the probe and the uterine wall for maximum heat transfer therebetween.

30 BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 illustrates a system constructed in accordance with the principles of the present invention.

Fig. 2 is an exploded view of a cryosurgical probe of the system of Fig. 1.

35 Fig. 3 is a detailed, cross-sectional view of a proximal end of a heat exchanger incorporated into the probe of Fig. 2.

Fig. 4 is a cross-sectional view taken along line 4-4 of Fig. 3.

Fig. 5 is a cross-sectional view taken along line 5-5 of Fig. 3.

5 Fig. 6 is a detailed, cross-sectional view of a distal end of the heat exchanger of the probe of Fig. 2.

Fig. 7 is a cross-sectional view taken along line 7-7 of Fig. 6.

10 Fig. 8 is a detailed, cross-sectional view of the distal tip of the probe of Fig. 2.

Fig. 9 is a schematic illustration of the refrigerant flow between the compressor and probe of Fig. 1.

Figs. 10A-10D illustrate the various operating modes of the system of Fig. 1.

15 Figs. 11, 11A and 12 illustrate a test system whose operation is described in the Experimental section.

DESCRIPTION OF THE SPECIFIC EMBODIMENTS

Referring to Fig. 1, a cryosurgical system 10 constructed in accordance with the principles of the present invention comprises a probe assembly 12 connected to a compressor 14 by a flexible umbilical tube 16. The compressor 14 will include a reservoir of refrigerant, a compressor, valving, and digital and analog control circuitry for controlling the mechanical components to produce up to three recirculating refrigerant streams, as described in more detail below. The refrigerant streams will be directed from the compressor 14 to the probe assembly 12 through individual conduits within the umbilical tube 16. Generally, all streams flowing through the umbilical tube 16 will be at or close to room temperature, minimizing the need for insulation of the tube. Details of the refrigerant flows will be described hereinafter.

35 The probe assembly 12 is best illustrated in Fig. 2 and includes a canister 20 having a proximal end 22 and distal end 24. The umbilical tube 16 enters the canister through its proximal end 22 and is connected to a helical heat exchanger 26, as will be described in greater detail in connection with

Fig. 3 below. The tube which comprises the helical heat exchanger 26 continues distally out through distal end 24 of the canister 20, identified at reference numeral 30. The tube 30 expands at its distal end 32, typically having a diameter of about 3 mm to 8 mm and a length of about 2 cm to 7 cm.

Tubular extension 36 of the canister 20 extends over a major portion of the length of the probe extension 30, typically covering 15 cm to 30 cm. Tubular extension 36 is open to the interior of canister 20, and preferably a vacuum will be held and sealed within the combined interiors of the canister and the tubular extension. Such vacuum provides good insulation of both the heat exchanger 26 and the portions of the probe 30 which are not intended for contacting tissue. Moreover, by combining the relatively small volume within the tubular extension 36 with the relatively large volume in canister 20, loss of the vacuum through out-gassing is greatly diminished.

A removable sheath 40 is received over the exterior of the probe extension 30/32 and can be attached to a proximal end of the canister 20 via a connector 42. Preferably, a heat-conductive material will be introduced into the interior of sheath 40 so that it spreads uniformly over the exterior of the probe 30/32 in order to enhance the conductivity. Preferred heat-conductive materials comprise heat-conductive powders suspended in a suitable liquid, such as diamond or graphite powders present in glycerol or other suitable carriers.

Referring now to Figs. 2-5, the umbilical tube 16 provides a total of four fluid-conductive paths or conduits between the compressor 14 and the probe assembly 12. In particular, a low boiling point refrigerant line 50 is provided for supplying the primary refrigerant stream to the tissue-contacting surface of the probe assembly 12. A secondary refrigerant line 52 is provided for supplying high boiling point refrigerant to the heat exchanger 26, and a third line 54 is provided for supplying refrigerant for warming the probe, as described in more detail below. Refrigerant from each of the lines 50, 52, and 54 provided to

the probe assembly 12 is returned from the probe assembly to the compressor 14 through the interior of the umbilical tube 16 itself. Thus, a total of four flow paths are provided.

5 The heat exchanger 26 comprises an outer stainless steel tube or shell 56 and an interior copper tube 58. The inner tube 58 is mounted concentrically within the shell 26 and held in place by spiral ridges 60 formed on the exterior of the copper inner tube 58. The ridges 58 define a flow path for the secondary pre-cooling refrigerant stream as described
10 below. The combination of shell 56 and inner tube 58 is wound into the helical coil best observed in Fig. 2. The high boiling point refrigerant line 50 opens directly into the distal end of the inner tube 58, and the secondary refrigerant line 52 passes concentrically through the entire length of the
15 inner tube 58 to its distal end, as described in more detail in connection with Fig. 6 below. The interior of inner tube 58 thus serves as a conduit for passing the primary refrigerant through the heat exchanger 26 while the annular space between the exterior of inner tube 58 and the interior
20 of shell 60 acts as a flow path for returning expanded secondary refrigerant for cooling the heat exchanger 26. The third refrigerant line 54 passes out from the umbilical tube 16 into the interior of canister 20 and bypasses the heat exchanger 26, as best seen in Fig. 2. It will be appreciated
25 that the refrigerant in line 54 is the "warm" fluid for warming the tissue-contacting surface of probe assembly 12, as described in more detail below. Thus, cooling of line 54 is to be avoided.

Referring now to Figs. 6 and 7, the heat exchanger
30 26 exits through the distal end 24 of the canister 20 and again assumes a straight configuration. At some point outside of the canister 20, warming line 54 reenters the extension 36 of the probe. The inner tube 58 terminates at a distal end 62 and the secondary refrigeration line 52 terminates in an
35 expansion orifice 64 in the form of a capillary. Thus, a refrigerant flowing through line 52 will flow into the interior of the heat exchanger shell 26 and will flow proximally back over the exterior of the inner tube 58 to cool

the tube 58. The low boiling point refrigerant which had been within the main lumen of inner tube 58 flows into a transition tube 66 and then into an expansion tube 68 which extends all the way to the tip 70 of the probe assembly 12, as best illustrated in Fig. 8. It will be appreciated that the low boiling point refrigerant that had been passing through the main lumen of inner tube 58 will have been cooled as a result of pre-cooling of the tube by the secondary refrigerant flowing from line 52. The third refrigerant line 54 (which has bypassed the main portion of the heat exchanger) will also pass through the shell 56 to the distal tip 70 of the probe assembly, as also shown in Fig. 8. The tube 54 comprises a pair of concentric tubes with the inner tube 72 passing gas into the outer tube 54 with no or partial expansion so that the tube is heated by the refrigerant flow. The return flow of refrigerant through tube 54 will eventually be recombined with the other refrigerants in the return lumen of umbilical tube 16. Thus, probe assembly 12 can be operated in a first cooling mode where the low boiling point refrigerant is expanded from the distal tip of expansion line 58, as shown by arrows 74 in Fig. 8. Alternatively, the high boiling point refrigerant flow can be terminated, and the probe tip 70 operated in a warming mode by passing a warm refrigerant through inner tube 72 into line 54 so that the refrigerant does not expand and can act to warm the probe.

Referring now to Fig. 9, refrigerant flow within the system 10 of the present invention will be described in general. The compressor 14 comprises a compressor unit 100, an oil separator 102, a capillary 104 that returns separated oil to the compressor unit 100, an air-cooled condenser 106, and a two-stage separator 108. Valves 110, 112, and 114 are provided to control the flow of refrigerant from the compressor 14 to the probe assembly 12. The two-stage separator 108 comprises a lower cyclone section for separating the incoming cooled, condensed refrigerant into a liquid phase which flows downward to line 116 and a vapor phase which flows upward to line 118. A portion of the upward vapor flow, however, will be condensed by returning cooled refrigerant

through line 116 which is coiled around the upper section of the separator 108. Thus, the liquid refrigerant passing outward through line 116 and vapor refrigerant 118 passing upwardly through line 118 will be in equilibrium. The thermodynamics of this system are discussed in detail in U.S. Patent Nos. 5,644,502 and 5,617,739, which have been previously incorporated herein by reference. The liquid refrigerant passes through valve 114 and line 52 into the heat exchanger and terminates in the expansion orifice/capillary 64, as described previously. Control of valve 14 determines whether or not flow of this refrigerant stream to the probe assembly 12 is established. The refrigerant vapor 118 passes either through valve 112 and through line 50 to the heat exchanger, as described previously, or through valve 110 and line 54 to the probe heating section 72, also as previously described.

Operation of the system 10 for the standby (pre-cooling) and cooling modes will now be described in connection with Figs. 10A-10D. System 10 is pre-cooled so that the heat exchanger in canister 20 is maintained at a low temperature, preferably minus 60°C or lower, by running the compressor to recirculate the refrigerant through air cooler 106 and into separator 108. In the pre-cooling mode, both overhead outlet valves 110 and 112 will be closed so that all flow of a refrigerant passes out through line 116, valve 114, line 52, and through the expansion orifice 64 to cool the heat exchanger. The expanded refrigerant from expansion orifice 64 will thus flow back through the heat exchanger and tube 16 and over the coils 120 and eventually back through return line 122 to the compressor unit 100. The system 10 may be operated in the standby or pre-cool mode for as long as desired and until steady state is achieved and the probe is to be contacted against tissue for therapeutic cooling.

In order to cool the probe, after pre-cooling of the heat exchanger 26 has been achieved, valve 112 may be opened as illustrated in Fig. 10B. Opening of valve 112 permits the primary low boiling point refrigerant stream to pass through line 50 and expansion orifice 68 into the probe tip 70. The

expansion of the refrigerant in the probe tip causes very rapid cooling, typically to a temperature at or below minus 100°C after a very short time, typically several minutes or less. The cooled, expanded refrigerant is then passed back to the compressor unit 100 through return line 16 together with the secondary refrigerant from valve 114 and line 52.

In an alternative cooling mode, the valve 112 may remain open to cool the probe tip 70, but the pre-cooling is terminated by closing valve 114, as illustrated in Fig. 10C.

After a cycle of cooling has been completed, it is often desirable to warm the probe tip. Warming of the probe tip may be accomplished using refrigerant from overhead line 118, as illustrated in Fig. 10D. This is done by opening valve 110 and closing valves 112 and 114, as illustrated. The refrigerant from overhead line 118 is generally at about room temperature and will provide sufficient warming of the probe 70 for most purposes. If greater warming is desired, it will be possible to access the hot refrigerant after being heated by compression in the compressor unit 100 and prior to being cooled in condenser 106. This alternative flow path is shown in broken line 130 in Fig. 10D. In either case, the warm or hot refrigerant will pass through line 54 to section 72 in probe tip 70 in order to provide the desired warming. The refrigerant will then return via conduit 16 as with all other refrigerants, back to the recirculating refrigeration system of compressor 14.

The following experiments are offered by way of illustration, not by way of limitation.

EXPERIMENTAL

A seven tube heat exchanger, as shown in Figs. 11, 11A, and 12 was constructed and included a copper capillary tube 200 having an outside diameter of 1.57 mm and an inside diameter of 1.17 mm surrounded by six additional copper capillary tubes 202, each having an outside diameter of 1.02 mm and an inside diameter of 0.51 mm. The capillary tube assembly was enclosed in a stainless steel outer tube 204

having an outer diameter of 6.35 mm and an inside diameter of 5.94 mm. The entire assembly was wound into a helical coil, as shown in Fig. 12. the inner capillary tube 200 feeds liquid from a liquid-vapor separator (as described above) and terminates at a point 203.2 cm from the warm end. This defines a flow restrictor which is equivalent to orifice 64 in Fig. 9. After expansion, low pressure liquid and vapor from the termination point of capillary 200 return to a compressor through the annular space between the outer surface of the seven capillary tube assembly and the inner wall of the stainless steel tube 204.

The heat exchanger was tested with a gas mixture as follows:

<u>Component</u>	<u>Weight Fraction</u>
Trifluoroethane	0.211
Tetrafluoromethane	0.320
HCFC123	0.180
Argon	0.150
CHCF ₅	0.126
CF ₃ CH ₂ F	0.013
	<hr/> 1.000

A Danfloss FF10GX compressor with a 9.05 cm³ displacement provided an approximately 310 cm³/sec flow to the heat exchanger. The results for two freeze and one thaw cycles are shown below.

<u>Mode</u>	<u>Freeze 1</u>	<u>Freeze 2</u>	<u>Thaw</u>
Low pressure, Psig	19	12	18
High pressure, Psig	300	300	390
Heat exchanger temperature, C	-100	-141	-130
Cold Probe temperature, C	-127	-127	37
Compressor temperature, C	67	67	70
Room temperature, C	22	22	22

While the above is a complete description of the preferred embodiments of the invention, various alternatives, modifications, and equivalents may be used. Therefore, the above description should not be taken as limiting the scope of the invention which is defined by the appended claims.

5

WHAT IS CLAIMED IS:

- 1 1. An improved system for treating tissue, said
2 system being of the type including:
3 a compressor which produces a recirculating
4 refrigerant stream; and
5 a probe having a tissue-contacting surface and a
6 primary expansion orifice, wherein the probe is connected to
7 the compressor to receive high pressure refrigerant, to pass
8 said high pressure refrigerant through the primary expansion
9 orifice to produce cooling of the tissue-contacting surface,
10 and to return a resulting low pressure refrigerant to the
11 compressor;
12 wherein the improvement comprises:
13 means for selectively circulating a warm fluid from
14 the compressor through the probe to warm the tissue-contacting
15 surface.
- 1 2. An improved system as in claim 1, wherein the
2 circulating means comprises a conduit from the compressor to
3 the probe for passing but not expanding or only partially warm
4 refrigerant past the tissue-contacting surface.
- 1 3. An improved system as in claim 2, further
2 comprising a controller which terminates passage of the high
3 pressure refrigerant through the primary expansion orifice and
4 initiates flow of the warm refrigerant past the tissue-
5 contacting surface in the probe.
- 1 4. An improved system for treating tissue, said
2 system being of the type including:
3 a compressor which produces a recirculating
4 refrigerant stream; and
5 a probe having a tissue-contacting surface and a
6 primary expansion orifice, wherein the probe is connected to
7 the compressor to receive high pressure refrigerant, to pass
8 said high pressure refrigerant through the primary expansion

9 orifice to produce cooling of the tissue-contacting surface,
10 and to return a resulting low pressure refrigerant to the
11 compressor;

12 wherein the improvement comprises:

13 a heat exchanger disposed to pass at least a portion
14 of the recirculating refrigerant stream from the compressor to
15 the tissue-contacting surface in the probe; and

16 means for pre-cooling the heat exchanger prior to
17 passing said portion of the recirculating refrigerant to the
18 tissue-contacting surface.

1 5. An improved system as in claim 4, wherein the
2 means for pre-cooling comprises a secondary expansion orifice
3 in the heat exchanger and a conduit for passing a portion of
4 the refrigerant stream to said secondary expansion orifice.

1 6. An improved system as in claim 5, wherein the
2 heat exchanger and the probe are present in a hand-held
3 assembly.

1 7. An improved system as in claim 6, wherein the
2 heat exchanger comprises a coiled shell with at least one
3 coiled inner tube, wherein the high pressure refrigerant
4 passes through the inner tube in a direction toward the probe
5 and the expanded refrigerant stream portion passes in an
6 opposite direction in an annular space between the inner tube
7 and shell.

1 8. An improved system for treating tissue, said
2 system being of the type including:

3 a compressor which produces a recirculating
4 refrigerant stream; and

5 a probe having a tissue-contacting surface and a
6 primary expansion orifice, wherein the probe is connected to
7 the compressor to receive high pressure refrigerant, to pass
8 said high pressure refrigerant through the primary expansion

9 orifice to produce cooling of the tissue-contacting surface,
10 and to return a resulting low pressure refrigerant to the
11 compressor;

12 wherein the improvement comprises:
13 a sheath adapted for removable placement over the
14 probe.

1 9. An improved system as in claim 8, wherein the
2 sheath is composed of a metal.

1 10. An improved system as in claim 8, further
2 comprising a heat conductive material between an exterior
3 surface of the probe and an interior surface of the sheath.

1 11. An improved system as in claim 10, wherein the
2 heat conductive material comprises a heat conductive powder
3 suspended in a liquid carrier.

1 12. An improved system as in claim 11, wherein the
2 clearance between the probe exterior surface and the sheath
3 interior surface is less than 0.15 mm.

1 13. An improved system for treating tissue, said
2 system being of the type including:
3 a compressor which produces a recirculating
4 refrigerant stream; and

5 a probe having a tissue-contacting surface and a
6 primary expansion orifice, wherein the probe is connected to
7 the compressor to receive high pressure refrigerant, to pass
8 said high pressure refrigerant through the primary expansion
9 orifice to produce cooling of the tissue-contacting surface,
10 and to return a resulting low pressure refrigerant to the
11 compressor;

12 wherein the improvement comprises:
13 a vacuum enclosure extending over all exterior
14 portions of the probe except for the tissue-contacting
15 surface.

1 14. An improved system as in claim 13, further
2 comprising a heat exchanger disposed to pass at least a
3 portion of the recirculating refrigerant stream from the
4 compressor to the tissue-contacting surface, wherein the heat
5 exchanger is also disposed within the vacuum enclosure.

1 15. An improved method for treating tissue of the
2 type comprising:
3 recirculating a refrigerant from a compressor to a
4 probe, wherein the refrigerant is expanded to cool a surface
5 in the probe;
6 contacting the cooled surface against tissue;
7 wherein the improvement comprises:
8 circulating a warm fluid from the compressor through
9 the probe to warm the tissue-contacting surface after it has
10 been cooled.

1 16. An improved method as in claim 15, wherein the
2 warm fluid is the recirculating refrigerant which is past
3 through the probe with no or partial expansion.

4 17. An improved method for treating tissue of the
5 type comprising:
6 recirculating a refrigerant from a compressor to a
7 probe, wherein the refrigerant is expanded to cool a surface
8 in the probe;
9 contacting the cooled surface against tissue;
10 wherein the improvement comprises:
11 pre-cooling a heat exchanger in the probe prior to
12 expanding the refrigerant; and
13 passing the refrigerant through the pre-cooled heat
14 exchanger to cool the refrigerant prior to expansion and
15 cooling of the probe.

1 18. An improved method as in claim 17, wherein the
2 pre-cooling step comprises passing a portion of the
3 refrigerant through an expansion orifice and directing the
4 cooled, expanded refrigerant through the heat exchanger.

1 19. An improved method as in claim 18, wherein the
2 temperature in the heat exchanger is lowered to minus 30°C or
3 below prior to passing probe refrigerant to the heat
4 exchanger.

1 20. An improved method as in claim 19, wherein the
2 probe is cooled to a temperature of minus 100°C or below.

1 21. An improved method for treating tissue of the
2 type comprising:

3 recirculating a refrigerant from a compressor to a
4 probe, wherein the refrigerant is expanded to cool a surface
5 in the probe;

6 contacting the cooled surface against tissue;

7 wherein the improvement comprises:

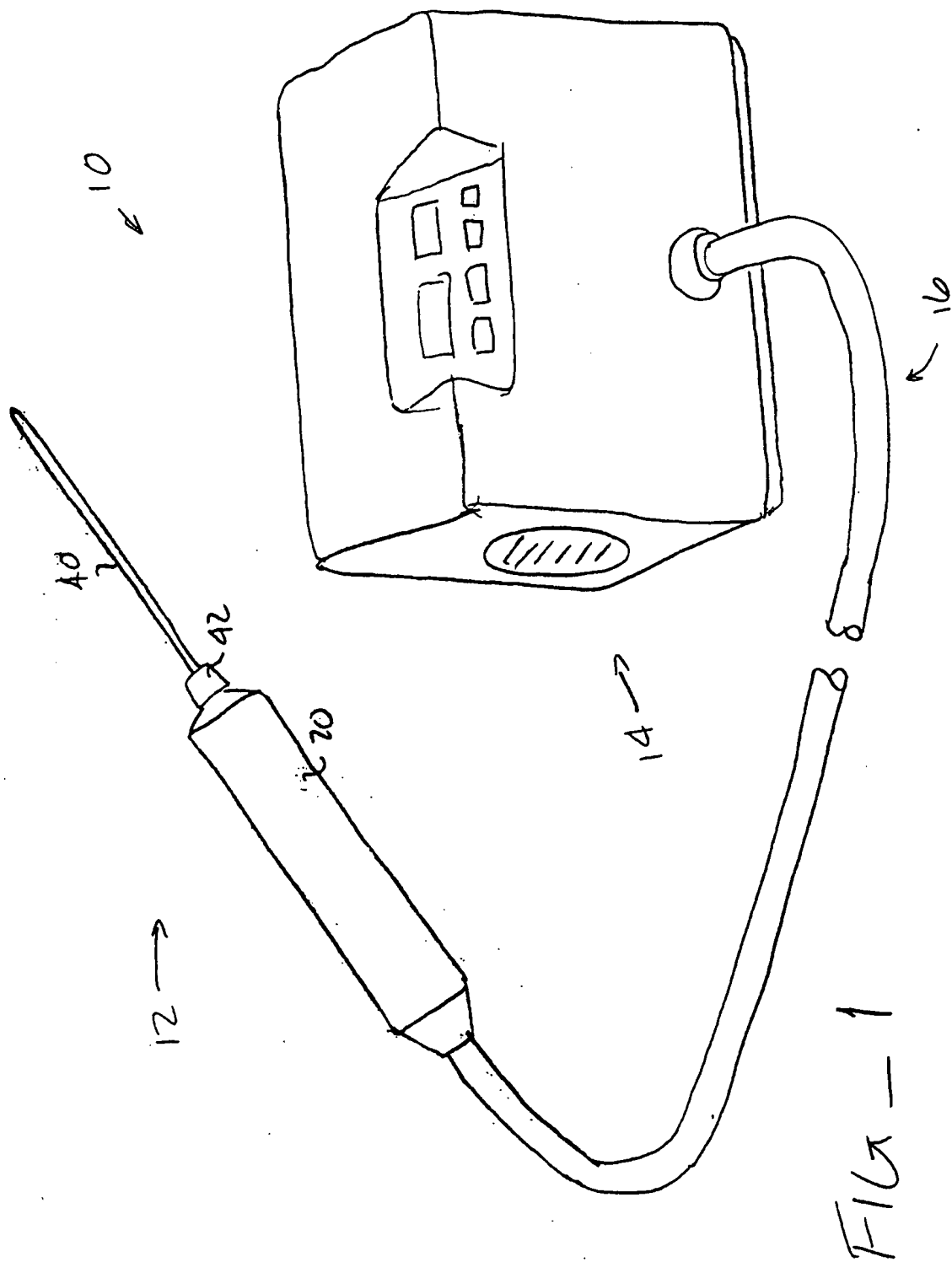
8 covering the probe with a sheath prior to contacting
9 the cooled surface against tissue.

1 22. An improved method as in claim 21, further
2 comprising placing a heat conductive material between an outer
3 surface of the probe and an inner surface of the sheath.

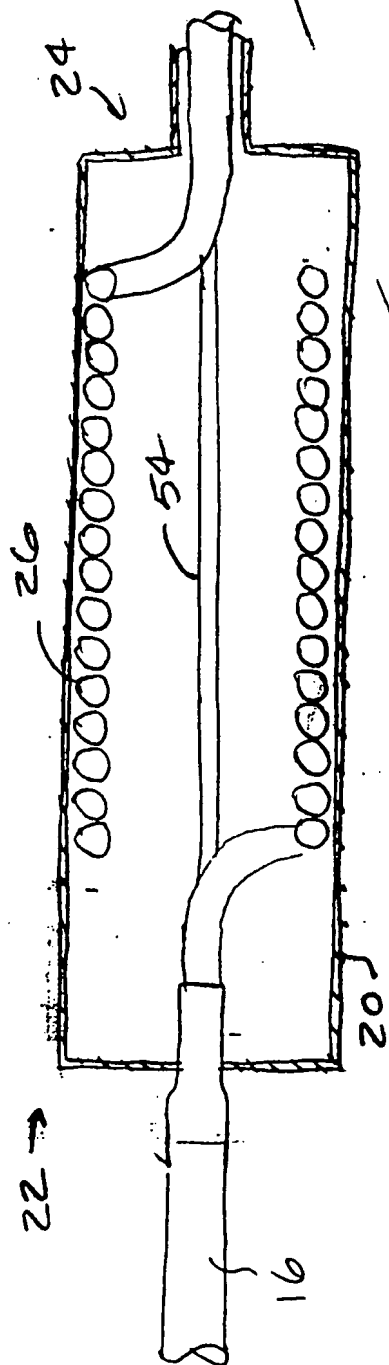
1 23. An improved method as in claim 22, wherein the
2 heat conductive material comprises a heat conductive powder
3 suspended in a liquid carrier.

1 24. An improved method as in claim 21, further
2 comprising placing a heat conductive material between an outer
3 surface of the sheath and the tissue.

1/11



12



2/11

32

30

36

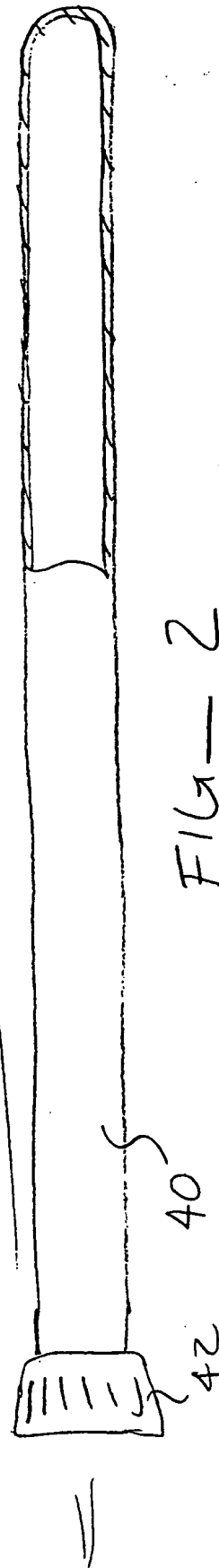


FIG. 2

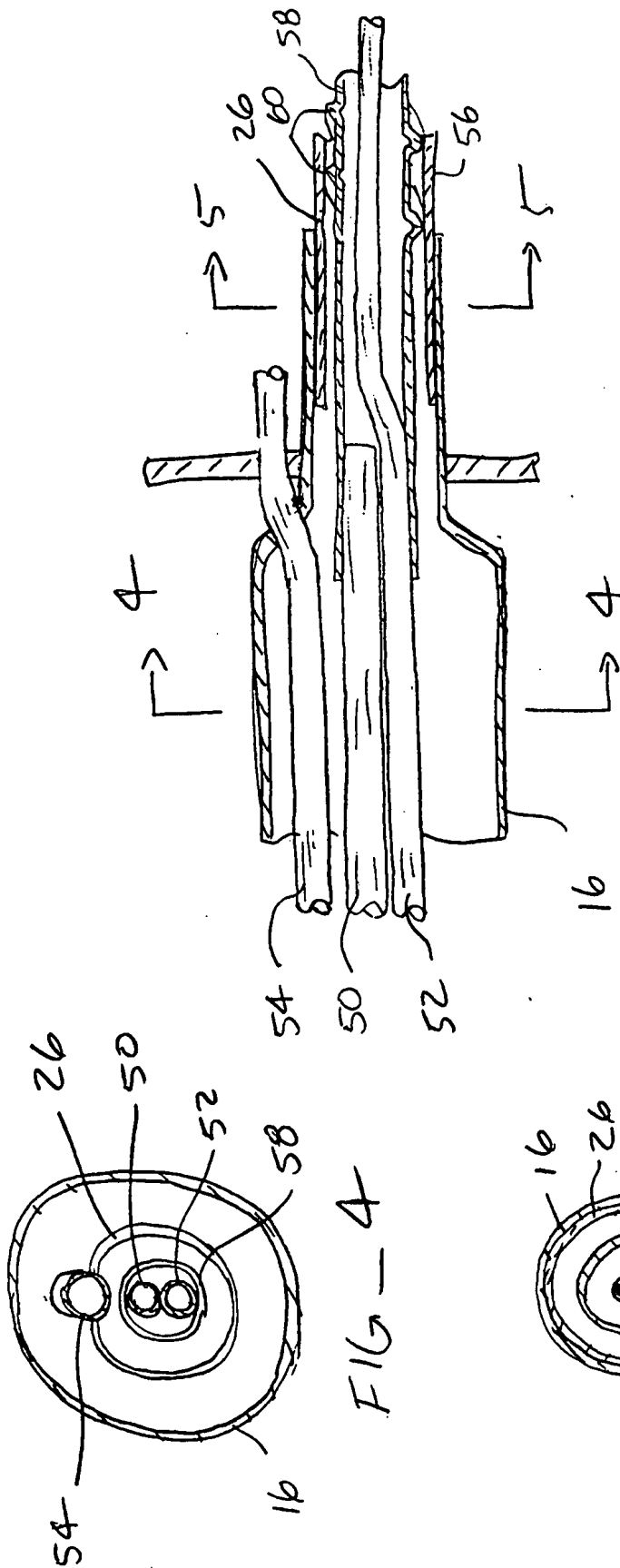


FIG-4

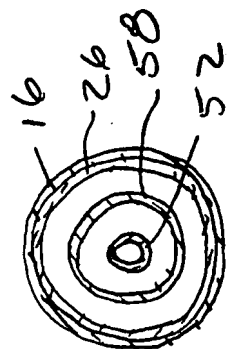


FIG-5

FIG-3

4/11

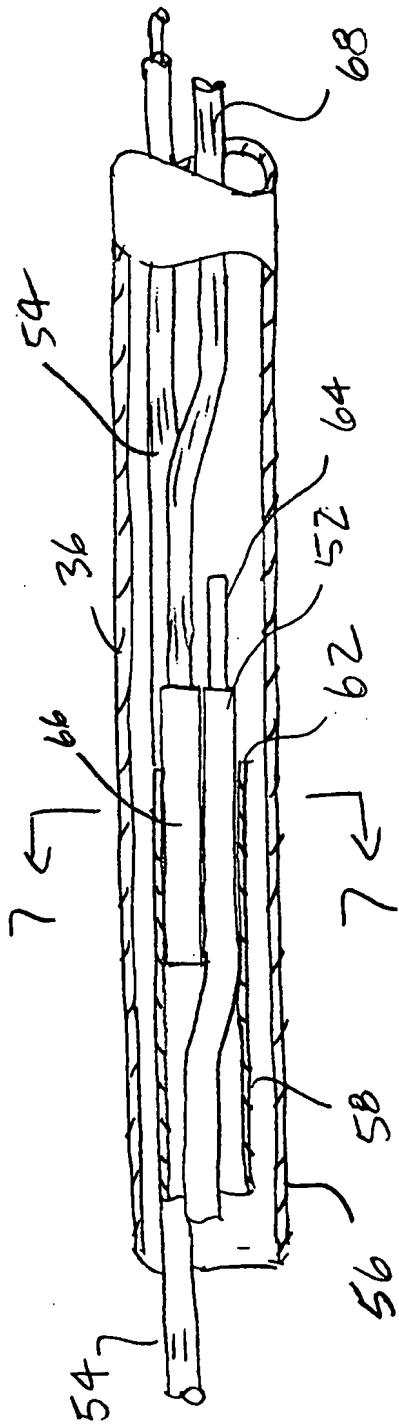


FIG. 6

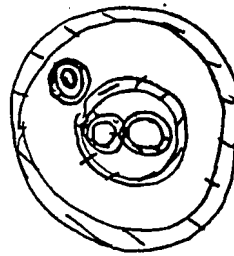
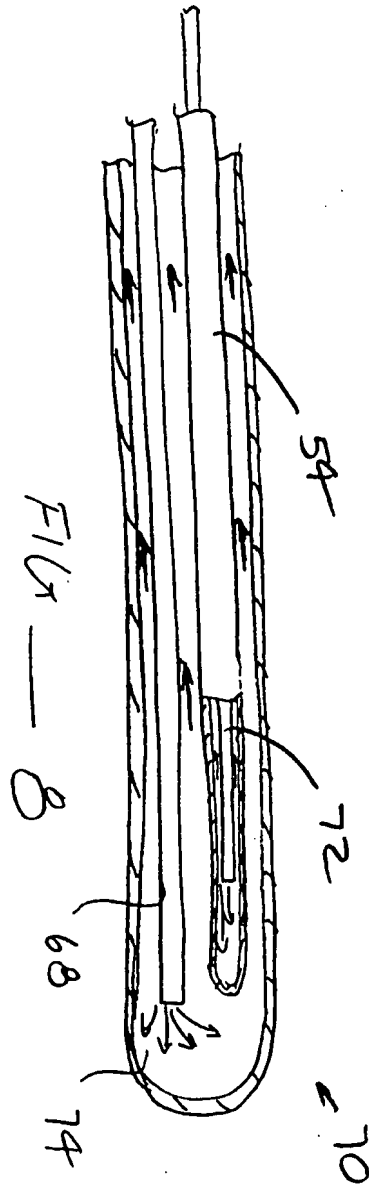


FIG. 7

5/11



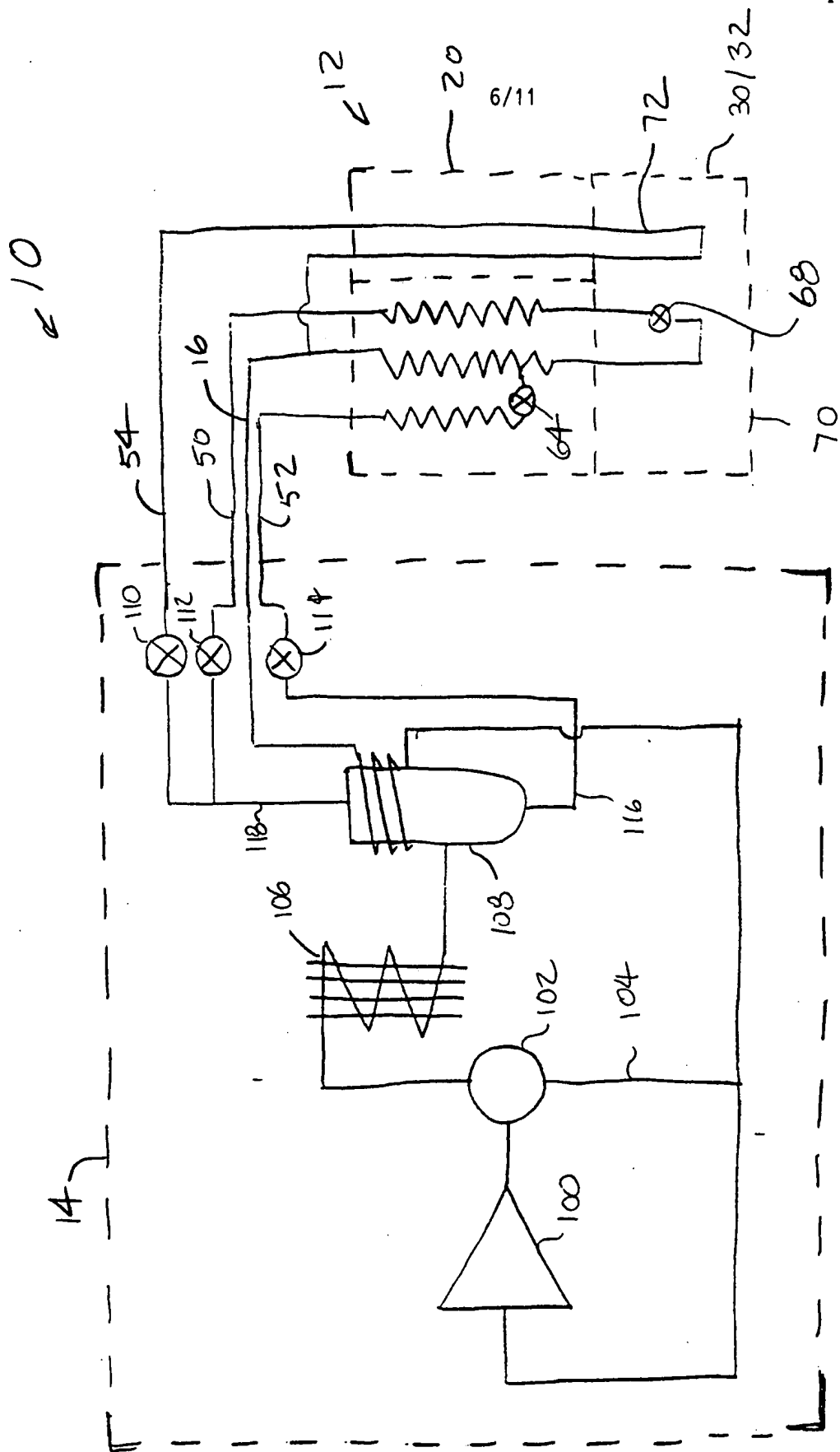


FIG-9

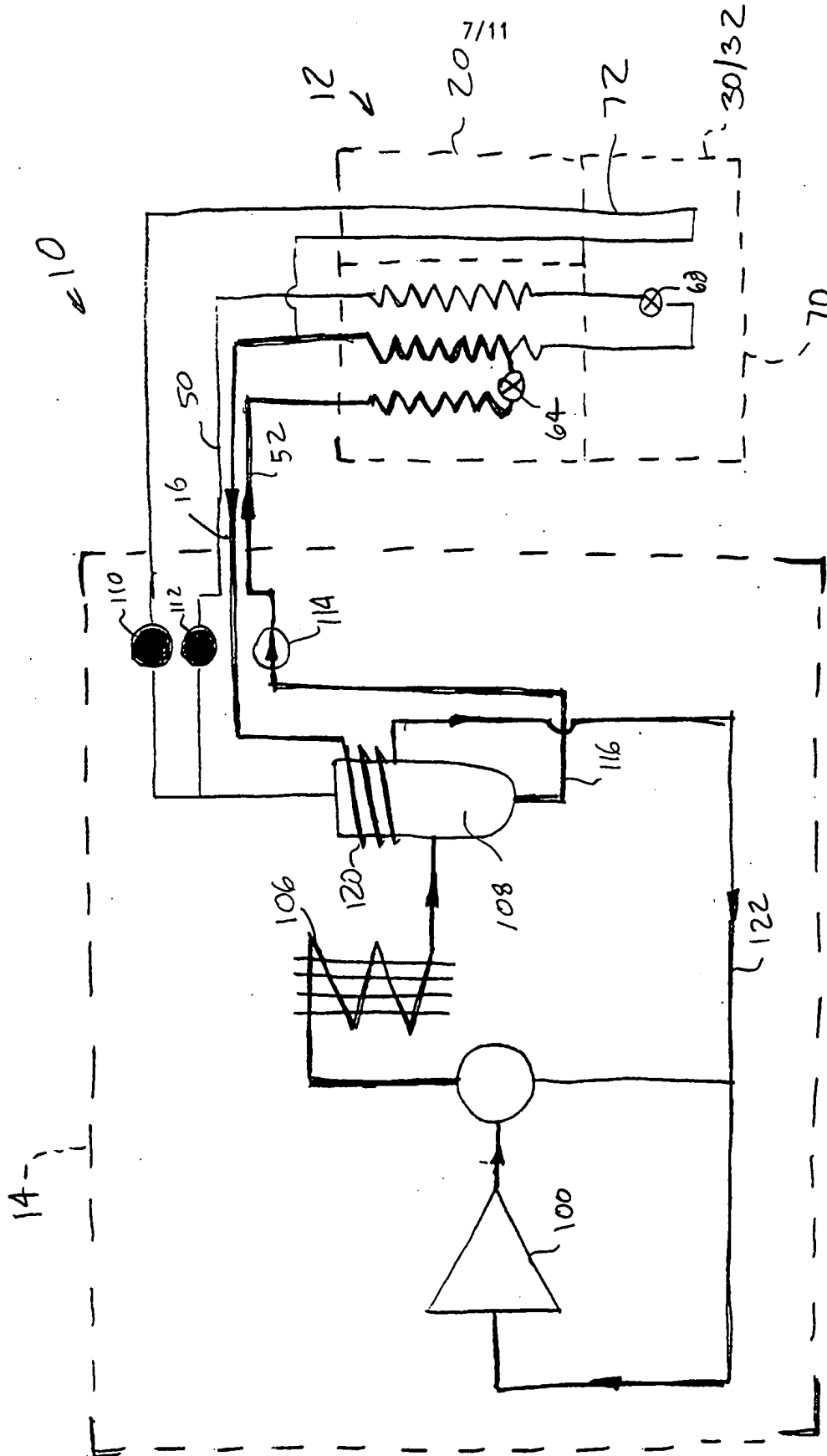


FIG-10A

8/11

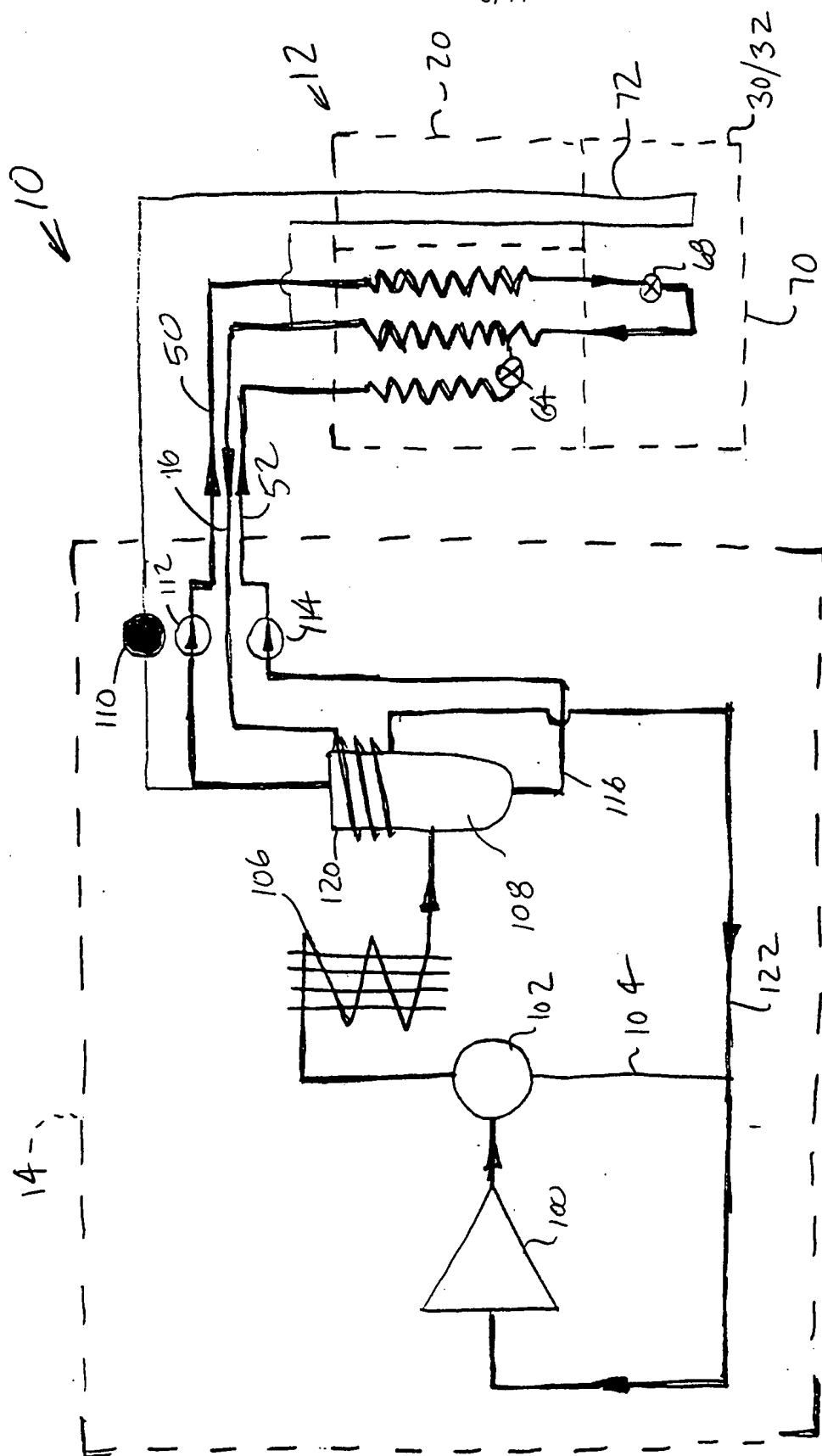


FIG-10B

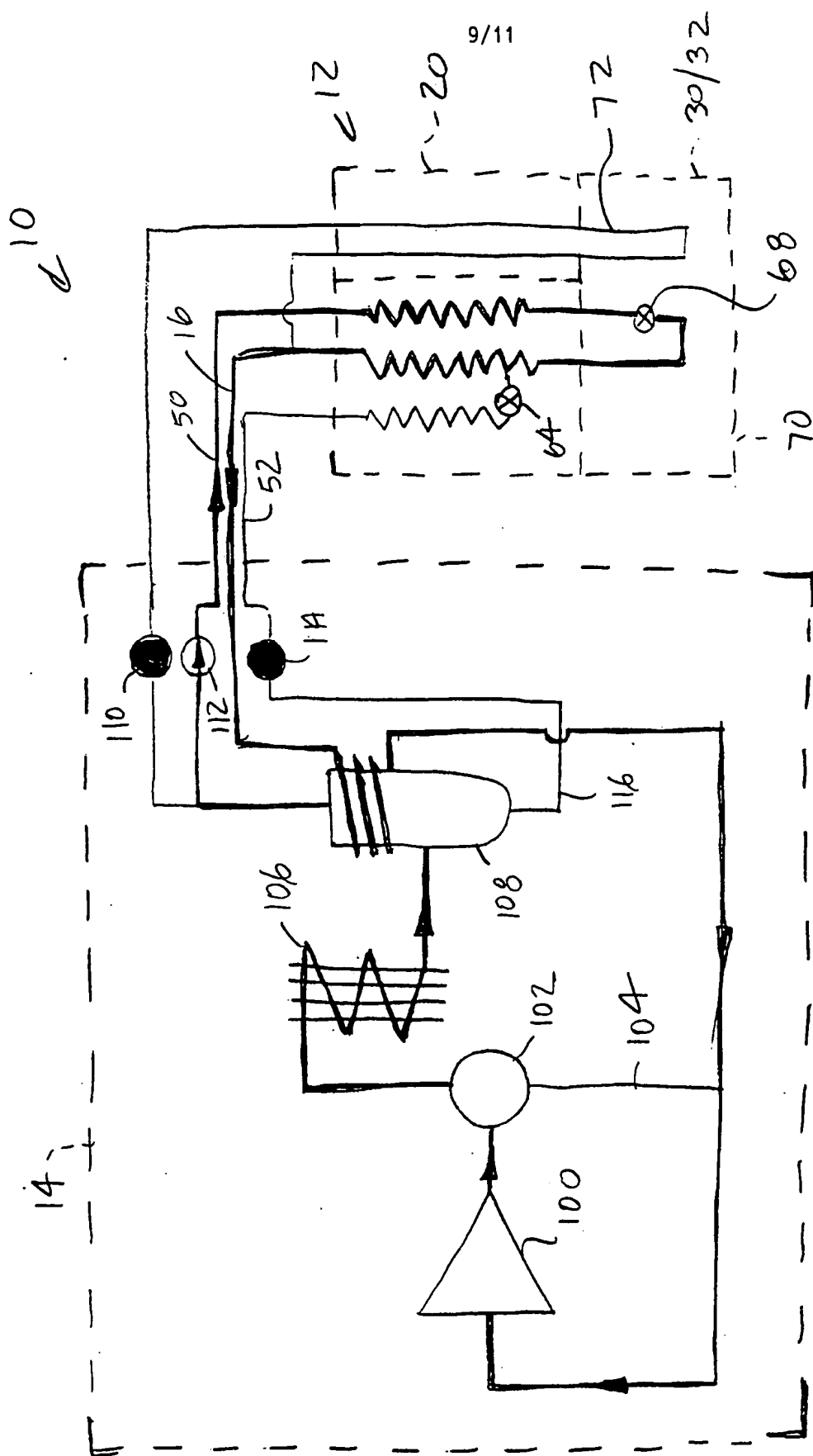


Fig-10C

10/11

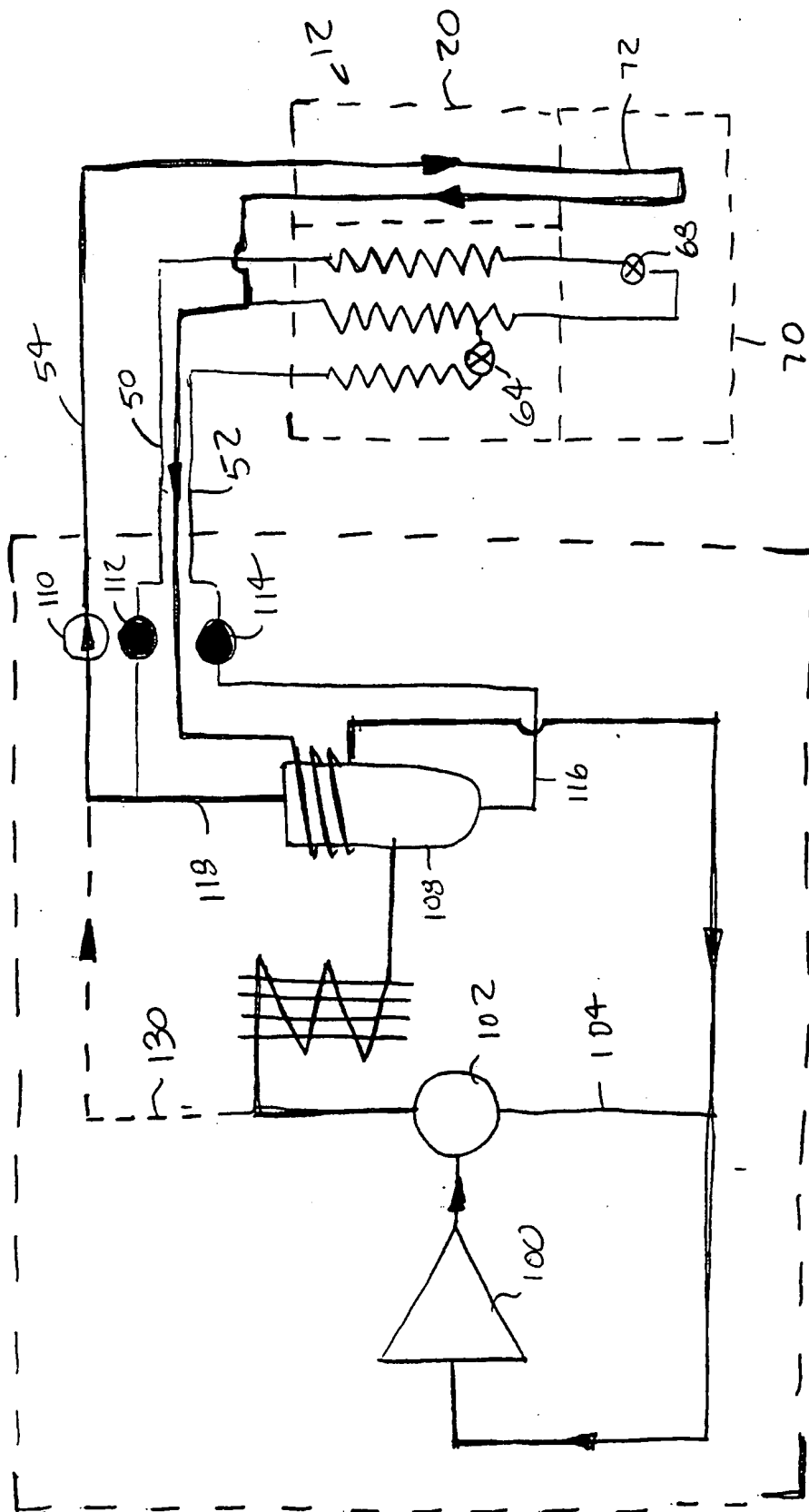
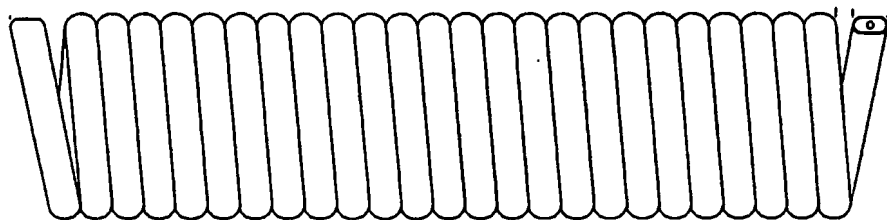
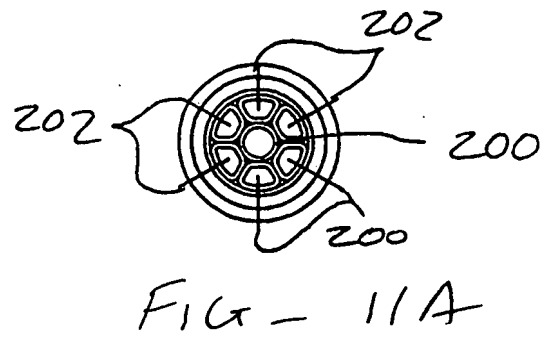
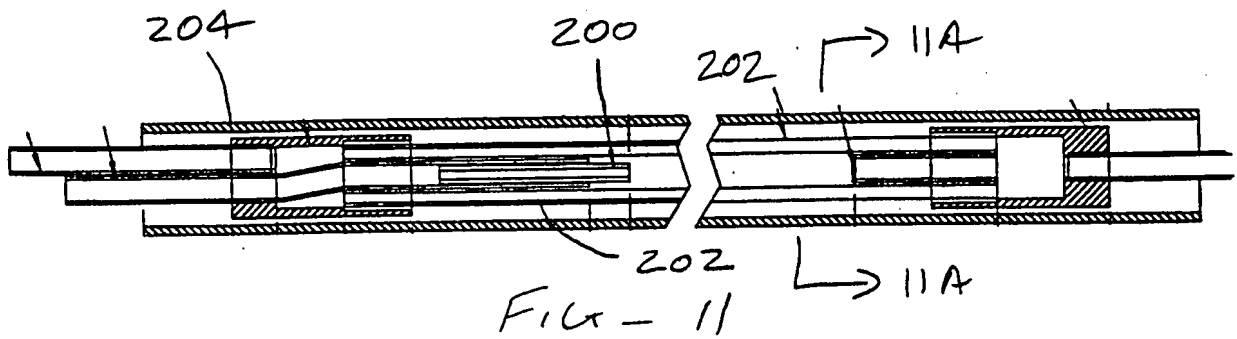


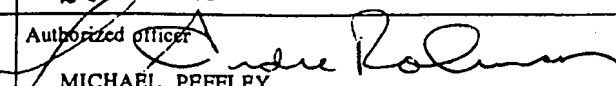
FIG-10D

11/11



INTERNATIONAL SEARCH REPORT

International application No.
PCT/US98/20033

A. CLASSIFICATION OF SUBJECT MATTER IPC(6) : A61B 17/36 US CL : 606/023 According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) U.S. : 606/020-026 Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched NONE Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) NONE		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X,P	US 5,800,488 A (CROCKETT) 01 September 1998, whole document.	1-7, 15-20
X	US 5,667,505 A (STRAUS) 16 September 1997, whole document.	1-6
X	US 5,632,743 A (CLARKE) 27 May 1997, whole document.	1-5, 15-20
X	US 3,859,986 A (OKADA) 14 January 1975, whole document (Fig. 1).	8, 9, 13, 21
A,P	US 5,674,218 A (RUBINSKY et al) 07 October 1997, whole document.	1-24
<input type="checkbox"/> Further documents are listed in the continuation of Box C. <input type="checkbox"/> See patent family annex.		
A	Special categories of cited documents: document defining the general state of the art which is not considered to be of particular relevance	*T* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
B	earlier document published on or after the international filing date	*X* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
L	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	*Y* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
O	document referring to an oral disclosure, use, exhibition or other means	*&*
P	document published prior to the international filing date but later than the priority date claimed	document member of the same patent family
Date of the actual completion of the international search 07 DECEMBER 1998		Date of mailing of the international search report 25 JAN 1999
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703) 305-3230		Authorized officer  MICHAEL PEFFLEY Telephone No. (703) 308-4305